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Comparison of Preemergence and Postemergence Weed Control Systems in Newly Established Pecan

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Six weed control programs with and without irrigation were investigated in a newly established pecan orchard. Irrigation increased crown diameter growth in only one of seven growing seasons but increased nut yield an average of 35% in the first two bearing years. Weed control program significantly influenced crown diameter beginning in the fourth growing season and continued through season six while also impacting final crown diameter. The use of postemergence (POST) herbicides increased crown diameter a minimum 4 mm vs. preemergence (PRE) herbicides. Mowing neither increased nor decreased crown diameter when used with herbicides; however, when used solely, crown diameter was 29% less. Highest growth rates were obtained with a combination PRE plus POST weed management system. Nut yields were closely linked to growth data. No differences in nut yield were observed between PRE- or POST-herbicide programs alone or in combination with mowing. Mowing alone decreased nut yield 57% vs. herbicide-based approaches. A combination PRE-plus POST-weed control program increased yield 38% vs. all other treatments.

Nomenclature: Pecan, *Carya illinoinensis* (Wang.) K. Koch var. 'Desirable'.
Key words: Mowing, drip irrigation.

Research has quantified the detrimental effects of weed competition on pecan (Arnold and Aldrich 1979; Foshee et al. 1997; Norton and Storey 1970; Patterson et al. 1990; Patterson and Goff 1994; Smith et al. 2005; Wolf and Smith 1999). Weeds compete for moisture and nutrients, and can decrease mechanical harvest efficiency (Goff et al. 1991; Norton 1970). Prior to the modern era of chemical weed control, pecan orchard management was limited primarily to disking and mowing near trees (Norton 1970). Both of these processes are expensive when compared to herbicides (Foshee et al. 1997) and can unknowingly contribute to other problems, such as increased crown gall (Cole 1969). Patterson et al. (1990) described the succession of weed species in pecan orchards with traditional mowing from broadleaved annual and perennial species to perennial grass species such as common bermudagrass [Cynodon dactylon (L.) Pers. CY-NDA]. Species such as these compete vigorously, and research has described that continuous mowing of grasses often poses no greater benefit to tree growth and yield when compared to no weed control (Patterson et al. 1990; Patterson and Goff 1994; Smith et al. 2002). More recent research has demonstrated that common bermudagrass exhibits allelopathic effects towards growth and development of young pecan (Smith et al. 2001).

Herbicide-based weed management programs have proven effective in controlling weeds, increasing growth, and improving yields of both young and older pecan trees (McEachern and Storey 1984; Norton and Storey 1970; Patterson et al. 1990). Furthermore, Foshee et al. (1997) demonstrated that herbicides increased economic return in newly planted pecan orchards. Norton (1970) first demonstrated the utility of residual herbicides such as simazine and diuron applied preemergence (PRE), or just prior to the start of a growing season. Broad spectrum herbicides such as glyphosate or paraquat are more cost-effective than graminicides such as clethodim, which can also be used in pecan (Patterson et al. 1990). Typical pecan weed management includes PRE herbicides and as-needed applications of postemergence (POST) herbicides such as glyphosate. Due to the wide spacing of trees compared to most other orchard crops ($>$ 10 m), complete vegetation control is generally undesirable and economically not feasible in pecan. Smith et al. (2005) and Faircloth et al. (2002) both described that vegetation free zones of 1.8 to 2.4 m surrounding the tree provided optimal growth and yield. Weed control beyond these areas gave no further benefit and increased cost significantly. The remaining inter-row area in an orchard is typically allowed to grow in perennial grass and mowed several times in the growing season.

Previous research by the authors has given conflicting results on the benefit of irrigation on young pecan. Although irrigation did increase growth (Patterson et al. 1990), the same trees showed no differences in yield in the first three bearing seasons (Patterson and Goff 1994). Additional data from the same experiment (Foshee et al. 1997) also showed no increase in crop value from irrigation. However, both of the aforementioned field studies took place in coastal Alabama, where rainfall frequently exceeds 1,800 mm/yr (Data provided by AWIS Weather Services, P.O. Box 3267, Auburn, AL, 36831–3267).

The case for chemical weed control in pecan is well-supported. The primary objective of this study was to compare PRE and POST herbicide systems for a newly established pecan orchard. These systems were compared with and without mowing and in both irrigated and nonirrigated

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Table 1. Herbicides, application timings, and rates.[a]

	1992–1993		1994–1995		1996–1998	
	PRE herbicide	Rate[b]	PRE herbicide	Rate	PRE herbicide	Rate
	oryzalin	2.24	simazine	2.24	diuron	3.36
	norflurazon	2.20	norflurazon	2.20	oryzalin	2.24
	glyphosate	1.25	paraquat	1.26	paraquat	0.84
	COC[c]	1.00	COC	1.00	NIS[d]	0.25
App.	POST herbicide		POST herbicide		POST herbicide	
1	glyphosate	1.25	paraquat	1.26	glyphosate	1.25
2	glyphosate	1.25	glyphosate	1.25	glyphosate	1.25
3	glyphosate	0.84	glyphosate	1.25	glyphosate	0.84
4	glyphosate	0.84	glyphosate	1.25	—	—

[a] Abbreviations: App., application number; COC, crop oil concentrate; NIS, nonionic surfactant.

[b] Rates given in kg ai/ha, except glyphosate (kg ae/ha) and adjuvants (% v/v).

[c] Prime Oil, Agriliance, LLC, St. Paul, MN 55164.

[d] Activate Plus, Agriliance, LLC, St. Paul, MN 55164

situations to determine any interactions that affect growth and nut yield.

Materials and Methods

The field study was completed on the Horticulture Research Unit of the E. V. Smith Research Center, located near Tallassee, AL. Soil at the location was a complex of Wickham and Cahaba sandy loams (fine-loamy, siliceous, semiactive, thermic Typic Hapludults) with pH 6.0 and organic matter 1 to 1.5%. The experimental area was naturally infested with the following weed species: common bermudagrass, yellow nutsedge (*Cyperus esculentus* L CYPES), arrowleaf sida (*Sida rhombifolia* L. SIDRH), and annual morningglory (*Ipomoea* spp.).

Orchard establishment began October 4, 1991, with planting of 'Desirable' pecan trees in rows spaced 12.3 m apart. Within-row spacing of trees was 9.2 m. The bare root, whip-grafted trees ranged from 15 to 20 mm in crown diameter (taken 15 cm above soil), with a mean of 16.8 mm. All trees were measured at planting and blocked according to similar size classes to ameliorate unwanted variation, with graft unions placed approximately at the same height above the soil. All herbicide applications and mowing commenced in the spring of 1992. Crown diameter was recorded annually in either December or January from 1992 through 1999. To assure measurement at the same location on the tree each year, a small nail was placed in the tree. Trees began to bear harvestable quantities of nuts in the sixth growing season (1998). Nuts were mechanically harvested in 1998 and 1999 and converted from a per tree quantity to a per ha basis, and reported as in-shell weights. Standard orchard establishment and maintenance practices such as fertilization and cultural considerations (e.g., pruning) were common to all trees through the duration of the study and were managed for optimum growth and nut yield (Daniell 1989; Goff 1989). Disease, especially pecan scab, and insect pests were managed for optimum growth and nut yield for the cultivar selected.

A factorial arrangement of irrigation and weed control program was implemented. Irrigation factors were irrigated and nonirrigated (dryland). Irrigation scheduling was achieved through pan evapotranspiration (ET) replacement at the 70% level according to Daniell (1989). Irrigation was applied daily via a drip system during the growing season unless rainfall was present. Weed control programs were: preemergence (PRE) herbicides only, PRE herbicides plus mowing, postemergence (POST) herbicides only, POST herbicides plus mowing, PRE and POST herbicides (no mowing), and mowing only (no herbicide). The PRE and POST herbicides and their rates are listed in Table 1 and were selected based on weed species/size, time of year, and age of pecan trees. All PRE herbicides were applied in admixture at the beginning of the growing season, ranging from late March through early April, depending on both soil and air temperature. PRE applications included glyphosate or paraquat to kill any remaining winter annual weeds present. POST herbicide applications were made on an as-needed basis, as the result of monthly scouting of the orchard, and began in May of each year. Herbicides were applied with a 3 nozzle CO_2-powered sprayer mounted on an all-terrain vehicle. All herbicides were applied in a water carrier at a total diluent volume of 187 L/ha. Mowing occurred on a 3-wk basis during the growing season and was accomplished using a gas-powered string trimmer to a height of 8 cm. Herbicides and mowing treatments were applied to a 1.5 m band on either side of a single pecan tree, giving a total treated area of 3 m wide (Faircloth et al. 2002; Smith et al. 2005). Between-row management (beyond the 3 m-wide treated strip) consisted of monthly mowing only.

Treatments were arranged in a split plot with whole plots in a randomized complete block design. The whole plot treatment factor was irrigation. Subplots were single trees to which one of the six weed control programs were randomly assigned. Eight replications of each treatment were included. The experimental unit was defined as a single tree and the 3-m-wide strip centered on that tree; thus herbicides and mowing treatments were confined to this area of influence.

Both tree growth and nut yields were subjected to analysis of variance with mixed models techniques to test for significance among and between the main effects of irrigation and weed control program (SAS 2003). Replication was used as a random term and variance partitioned accordingly. When no significant interactions were observed between main

Table 2. Factorial ANOVA results for crown diameter growth of pecan trees from establishment through the seventh season.[a]

Main effect or interaction	Season after planting 1	2	3	4	5	6	7	Final diameter
	P > *F*							
Treatment[b]	0.1538	0.0220	0.2932	< 0.0001	0.1146	0.0069	0.0179	0.0011
Irrigation (I)	0.4591	< 0.0001	0.6736	0.5097	0.9808	0.3443	0.9218	0.3440
Weed control program (W)	0.0523	0.1227	0.1629	< 0.0001	0.0157	0.0136	0.1065	< 0.0001
I × W	0.4042	0.3645	0.5032	0.8667	0.7479	0.3594	0.0528	0.1822

[a] Analysis of variance performed using mixed models techniques (SAS 2002); effects are considered significant if P ≤ 0.05.

[b] Treatment defined as any specific combination of irrigation and weed control program (12 total).

effects, data were combined for ease of presentation and discussion. Select preplanned nonorthogonal contrasts were identified as follows: mowed vs. nonmowed (among herbicide treatments), PRE herbicides vs. POST herbicides (inclusive of mowing), all herbicides vs. mowing only, and PRE plus POST herbicide vs. all other weed control programs. In addition to the above-identified contrasts, it was desirable to compare individual treatment means, where treatment is defined as a specific combination of irrigation and weed control program. In the absence of significant main effects or interaction, treatment means were combined. Treatments were separated where appropriate using Duncan's multiple range procedure. A P value of 0.05 was selected as the test of significance.

Results and Discussion

Neither weed control program nor irrigation affected growth in the first season after planting (Table 2). These results are typical of pecan; previous work has shown a two- to three-season lag in growth response to weed control measures (Patterson et al. 1990; Smith et al. 2005). Weed control significantly affected crown diameter beginning in the fourth season after planting and continued to impact growth through year six (Table 2). Weed control program also showed a difference in the final crown diameter. Irrigation increased crown diameter by 6 mm in the second season after planting only (data not shown). Through the remainder of the study, neither irrigation alone, nor its interaction with weed control program showed a significant difference in tree growth response. Yearly rainfall recorded at the experimental site gives an insight into irrigation response (Table 3). Rainfall at the experimental field was greater than the 30-yr mean for that area in all but two growing seasons. Drought beginning December 1992 and continuing through May 1993 resulted in a 16% deficit in rainfall during the second growing season. Understandably, irrigation was needed to overcome early-season stress factors. Patterson et al. (1990) also found irrigation increases growth of young pecan; however, nut yields were not affected (Patterson and Goff 1994). The present study represents a two degree increase in north latitude and a separation from the mitigating effects of the Gulf of Mexico vs. the orchard studied previously (Patterson et al. 1990; Patterson and Goff 1994).

Due to the lack of irrigation interactions with the exception of year two, weed control programs were pooled across irrigation treatments for further discussion and analysis (Table 4). Mowing as a supplement to herbicide-based weed control did not improve pecan growth. When used exclusively, mowing was not an effective management tool, because tree growth was 15 mm less in season four, and at least 5 mm less in the following seasons compared with herbicide programs. Trees that received mowing only as their form of weed control were 43 mm smaller at the conclusion of the study, representing a 29% decrease in crown diameter. This is in agreement with other research which has shown mowing to be an ineffective weed management tool in pecan, in fact, equivalent to no weed control at all in many instances (Foshee et al. 1997; Patterson et al. 1990). Mowing increases the presence of perennial grasses which are known to compete strongly with young pecan (Norton and Storey 1970; Patterson et al. 1990; Smith et al. 2001, 2002). Weed control programs that utilized POST herbicides only were greater than those programs that relied on PRE herbicides only, giving a minimum 4 mm increase in yearly growth and 24 mm increase in final crown diameter (Table 4). The same abundance of rainfall that made irrigation not significant, when combined with light soils, likely increased the

Table 3. Cumulative rainfall and deviation from the 30-yr mean 1992–1999: Horticulture Unit, Tallassee, AL.

	1992	1993	1994	1995	1996	1997	1998	1999
	mm							
Rainfall[a]	1,557	1,141	1,274	1,391	1,448	1,647	1,363	1,386
	%							
Deviation[b]	+15	−16	−6	+3	+7	+22	+1	+3

[a] Mean, 1,399 mm; standard deviation, 145 mm.

[b] 30-yr mean rainfall (1,351 mm) as recorded at nearby Milstead, AL, approximately 4.0 km south of the experiment station. Mean provided by AWIS Weather Services, P.O. Box 3267, Auburn, AL, 36831–3267.

Table 4. Annual crown diameter increase and final crown diameter after the sixth season as influenced by weed control program.[a]

Weed control program	Season after planting 4		5		6		Final diameter	
	mm							
PRE only	13 b		19 bc		16 cd		133 b	
PRE + mowing	14 ab		21 abc		17 bcd		141 ab	
POST only	22 a		22 abc		20 abc		157 ab	
POST + mowing	22 a		27 a		21 ab		164 a	
PRE + POST	22 a		24 ab		22 a		164 a	
Mowing only	4 c		17 c		14 d		109 c	
	Estimate[b]							
Mowing vs. no mowing	+1	0.8313	+4	0.0775	+1	0.5146	+8	0.3966
PRE vs. POST	−9	0.0047	−5	0.0208	−4	0.0069	−24	0.0067
Herbicide vs. mowing only	+15	< 0.0001	+6	0.0252	+5	0.0042	+43	< 0.0001
PRE + POST vs. other	+7	0.0234	+3	0.2591	+4	0.0182	+23	0.0118

[a] Data presented are pooled across irrigation main effect due to lack of significance and interaction (P = 0.05). Means within a column followed by the same letter are not significantly different according to Duncan's multiple range procedure (P = 0.05).

[b] Values are the estimated significant difference followed by the $P > F$ ($P \leq 0.05$); mowing vs. no mowing contrast is exclusive of PRE + POST only and mowing only treatments; PRE vs. POST contrast includes mowing.

Table 5. Factorial ANOVA results for nut yield of pecan trees in the sixth and seventh growing seasons.[a]

Main effect or interaction	Year 6 (1998)	Year 7 (1999)
	$P > F$	
Treatment[b]	0.0037	0.0003
Irrigation (I)	0.0716	0.0615
Weed control program (W)	< 0.0001	< 0.0001
I × W	0.9253	0.1523

[a] Analysis of variance performed using mixed models techniques (SAS 2002); effects are considered significant if $P \leq 0.05$.

[b] Treatment defined as any specific combination of irrigation and weed control program (12 total).

breakdown of herbicides such as oryzalin, simazine, and diuron (Arnold and Aldrich 1979; Norton, 1970; Vencill 2002), making repeated applications of broadspectrum herbicides necessary (Lipe 1986; Foshee et al. 1997; Patterson et al. 1990). Disking or some other soil incorporation technique could increase the persistence of some PRE herbicides such as norflurazon (Vencill 2002); however, such soil disturbances are known also to increase the risk of infection of *Agrobacterium tumefaciens*, the causal agent of crown gall (Cole 1969). Complete reliance on chemical weed control means increased pecan growth and resulted in larger trees at the study conclusion (Table 4).

Pecan nut yields were significantly affected by weed control program at P = 0.05 (Table 5). However, at P = 0.10, irrigation was significant. Given the longevity of this study and the alternate bearing nature of pecan, significance at this level cannot be discounted. Mean nut yield in 1998 for irrigated trees was 71 kg/ha compared with 48 kg/ha for nonirrigated; nut yields in 1999 for irrigated trees was 343 kg/ha compared with 280 kg/ha for nonirrigated (data not shown).

Due to the lack of a weed control program by irrigation interaction, yield data were pooled across irrigations for presentation and further analysis as done for growth (Table 6). Mowing in conjunction with herbicide-based weed

Table 6. Pecan nut yield in the sixth and seventh growing seasons as a function of weed control program.[a]

Weed control program	Year 6 (1998)		Year 7 (1999)	
	kg/ha			
PRE only	57 bc		287 b	
PRE + mowing	53 bc		315 ab	
POST only	56 bc		301 ab	
POST + mowing	70 ab		424 a	
PRE + POST	107 a		405 ab	
Mowing only	13 c		138 c	
	Estimate[b]			
Mowing vs. no mowing	+5	0.7194	+76	0.0755
PRE vs. POST	−8	0.6134	−62	0.1295
Herbicide vs. mowing only	+56	0.0013	+209	< 0.0001
PRE + POST vs. other	+57	0.0010	+112	0.0146

[a] Data presented are pooled across irrigation main effect due to lack of significance and interaction (P = 0.05). Means within a column followed by the same letter are not significantly different according to Duncan's multiple range procedure (P = 0.05).

[b] Values are the estimated significant difference followed by the $P > F$ ($P \leq 0.05$); mowing vs. no mowing contrast is exclusive of PRE + POST only and mowing only treatments; PRE vs. POST contrast includes mowing.

control did not increase nut yields in either 1998 or 1999. As a stand-alone treatment, mowing resulted in lower nut yields of 56 and 209 kg/ha in 1998 and 1999, respectively, vs. herbicide-only programs. Accordingly, no significant difference was determined between PRE-only and POST-only herbicides, however; a numerical advantage was seen with POST only in both years (8 and 62 kg/ha). The combination of PRE- and POST-herbicide programs was the superior choice of weed control based on nut yields; increases of 57 and 112 kg/ha were determined in 1998 and 1999, respectively, vs. all other weed control programs.

Results from this study illustrate the importance of POST herbicides in pecan orchard floor management. PRE herbicides resulted in less growth but equivalent nut yields when compared with POST herbicides. A PRE plus POST weed control program gave consistently high growth and yield for a newly established pecan orchard. POST herbicides plus mowing resulted in good growth and yield; however, Foshee et al. (1997) found use of herbicides were more economical than mowing. Our data clearly indicate the importance of weed management decisions in orchard establishment and further allude to the fact that weed control influences young pecan growth and yield as importantly as supplemental irrigation in the temperate climate of the southeastern United States.

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